DYNAMIC RESPONSE OF A WHEELSET TO VERTICAL FAULTS AT RAIL WELDS

J. DROŹDZIEL and B. SOWIŃSKI

Institute of Transport
Technical University of Warsaw
Koszykowa 75, 00–662 Warsaw, Poland

Received Nov. 10, 1992

Abstract

In this paper, localised vertical geometrical faults at rail welds are considered. The aim is to predict maximum permissible irregularity sizes at such faults, assuming continuously welded track. To achieve this, the criteria of maximum accelerations and dynamic peak-wheel-rail forces between welds can be used. Theoretical results were partly controlled by experiments and discussed in relation to other studies.

Keywords: wheelset dynamic, rail weld, fault tolerances.

1. Introduction

The modern railway track destined for high-speed traffic should satisfy travelling comfort requirements and safety.

Vertical irregularities in the vicinity of butt welds can generate additional transient disturbances, which are dependent on the shapes and sizes of weld faults. The weld faults may have greater effect on travelling comfort than irregularities between welds, and moreover, they can give rise to a stronger local effect in the form of track components deterioration and can bring about an increase in track maintenance costs.

In order to predict permissible fault sizes such as heights or depths, it has been assumed that peak acceleration values of a wheelset, when running over welds areas, are not greater than peak acceleration values between them.

The same criterion can be accepted for the maximum permissible vertical wheel-rail forces.

Regarding specific types of geometrical faults in the vicinity of welds, it is not possible to measure the effects for all desirable track and traffic combinations. A useful approach would be to derive a theoretical treatment of the effects which can cover a wide variety of welds, track and traffic.

To analyse these transient processes generated by the above specific irregularities, a particular approach is needed. Namely, dynamic model of the system should include elastic and damping properties of the track structural components [1, 3].

In can be observed that magnitudes of the wheelset and rail accelerations as well as wheel-rail contact forces are strongly affected by travelling speed and geometrical fault sizes at rail welds.

2. Types of Weld Faults

On the basis of the measured vertical irregularities in the area of weldment, we can divide them into two following types:

(1) Convex irregularities as humps
(2) Concave irregularities as hollows

These above two types dominated the PKP experimental section of railway track constructed for increased speeds.

For assessing the irregularities, measurements were performed using stationary instrument Geismar of type RM-1200. Its measuring range can vary within ± 1.5 mm and gauge length is equal to 1200 mm.

In all the cases of measurement, a weld was placed in the midpoint of a gauge length.

For all geometrical faults, measurement was performed twice: the first one on the top of rail head (*Figs. 1* and *2*, solid line), and the second one at a 10 mm position displaced towards the track centre (*Figs. 1* and *2*, dashed line).

One can notice that the differences between central and shifted irregularity profiles are negligible.

On the experimental track section, which was tested, the hump type of faults amounts to 75% of all the measured irregularities. It should be emphasized that humps are relatively easy to reduce by grinding off, but hollows are practically untreatable.

Figs. 1 and *2* illustrate typical geometrical irregularities representing experimentally measured humps and hollows.

They can be characterised with the aid of 2 parameters [2] as it is shown in *Fig. 3*.
For humps: h – max. height, ω – angle of refraction ($\omega > 0$).
For hollows: d – max. depth, ω – angle of refraction ($\omega < 0$).

To simplify our consideration, linear dependence between height/depth of faults and angle of refraction has been assumed: $\omega = \eta_1 \cdot h$ or $\omega = \eta_2 \cdot d$, where $\eta_{1,2} = \text{const}$. It is justified for relatively low heights/depths. Owing to this, it is possible to reduce computer calculations and to confine ourselves to one parameter variation. Please notice that the wavelengths

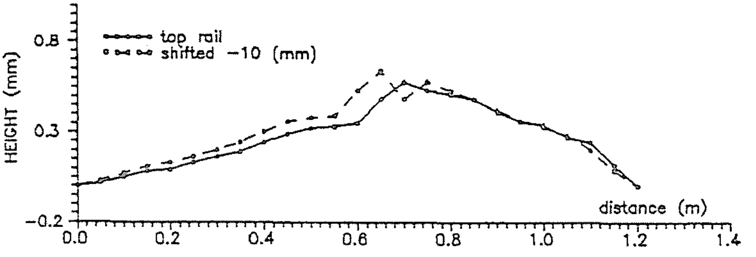

Fig. 1. Vertical hump irregularities (Weld S2L)

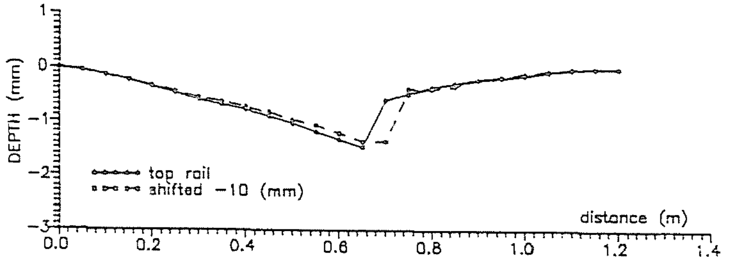

Fig. 2. Vertical hollow irregularities (Weld T2L)

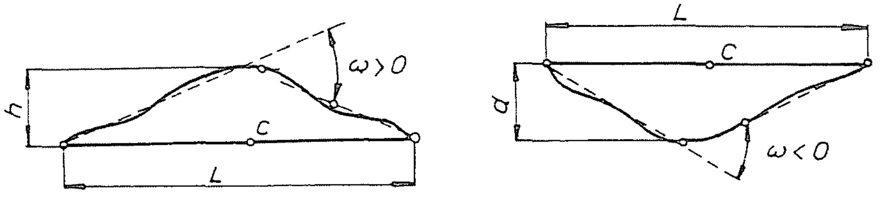

Fig. 3. a) hump, *b)* hollow; C — midpoint of gauge length (weld), L — gauge length

of irregularities in the weld areas are shorter than the wavelengths of real track roughness between welds, and it cannot be registered by a test-wagon.

3. Wheelset Acceleration on Experimental Track

In order to establish mean and peak values of unsprung mass acceleration when vehicle is moving over a track, an experiment was performed.

A few series were made for track supported on wooden sleepers (K) and for track on concrete sleepers (SB3) at 600 mm spacing. The experiment was carried out at a temperature of $+8°C$ and of $-10°C$. The elastic properties of track components, mainly those of ballast elasticity, are significantly affected by the temperature variations.

In *Fig. 4,* the measured mean vertical accelerations of the unsprung mass and their standard deviations are shown. The results were obtained by using low-pass filter 320 Hz.

At a negative temperature, higher level of accelerations and standard deviations takes place. In the range of the measurement, unsprung mass vertical accelerations were greater for tracks on concrete sleepers.

4. Wheelset-Track Dynamic Model

The calculation of dynamic response to geometrical weld faults can be based on a computer program CDS made by the authors of this paper for a multi-degree of freedom vehicle-track system. Nevertheless, a simplified seven degree of freedom model gives results sufficiently close to those of the complex model.

The calculations in this paper use the simpler theory and are consistent with the measured unsprung mass accelerations [2].

The theory is limited to linear track dynamics because non-linear one requires data which are not readily available.

In the track model rails, railpads, sleepers and ballast were reckoned with as represented by substitute values of masses and elastic damping elements related to the track on concrete sleepers (*Fig. 5*).

This model does not regard dynamic coupling between adjacent wheelsets through the rails. However, it can be used in the range of frequency vibrations up to 500 Hz [1], and a reasonable speed of a vehicle. The influence of travelling speed on the track parameter values is imperceptible and can be ignored [3]. Wheel-rail contact forces were calculated for real rail (UIC 60) and real wheel (S1002) profiles. Beyond the weld areas, the track is perfectly tangent.

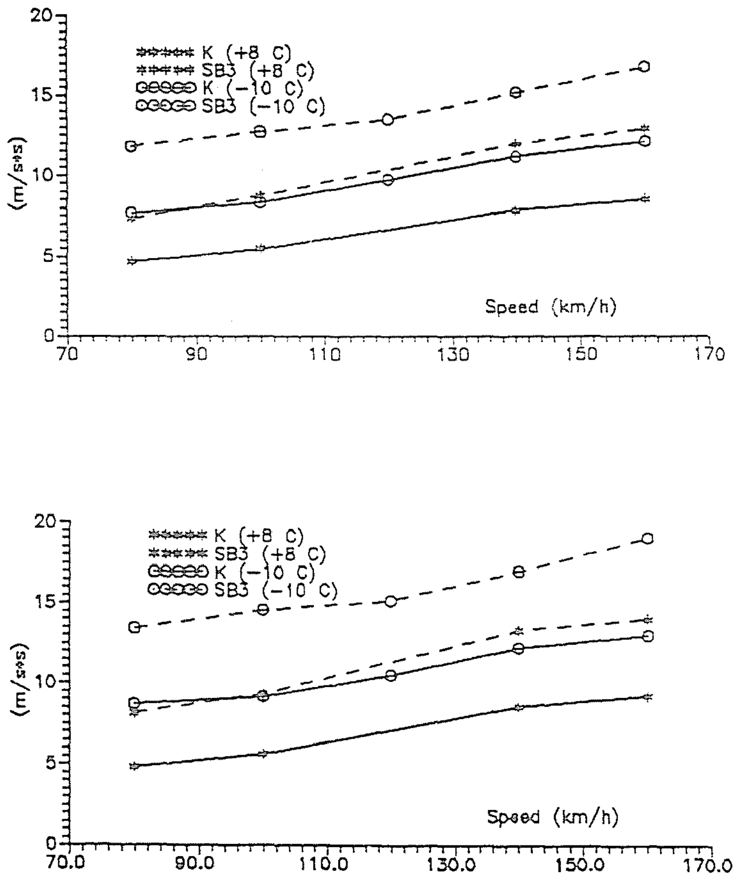

Fig. 4. *a*) Mean values of vertical unsprung mass acceleration, *b*) STD deviation of vertical unsprung mass acceleration

5. Prediction of Maximum Permissible Fault Sizes

The purpose of the computational prediction was to determine the maximum vertical unsprung mass accelerations and dynamic increments of vertical wheel-rail forces for various sizes of weld faults (± 0.1, ± 0.2, ..., ± 1.0 mm) and for a wide range of travelling speeds.

The curves in *Figs. 6 – 9* showing the course of peak accelerations and wheel-rail dynamic forces were approximated by the second order of polynomials using the method of least squares.

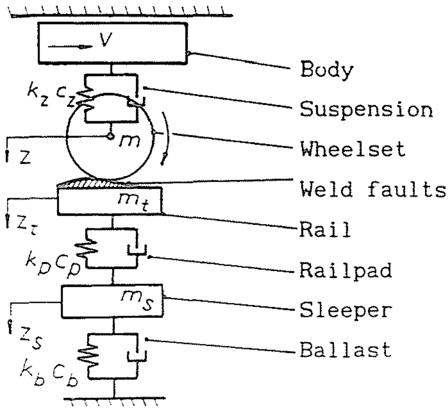

Fig. 5. Dynamic model
$$\begin{aligned} k_2 &= 2\,\mathrm{MN/m} \\ c_2 &= 0.014\,\mathrm{MNs/m} \\ m &= 2200\,\mathrm{kg} \\ m_t &= 60\,\mathrm{kg} \\ k_p &= 2.5\cdot 10^2\,\mathrm{MN/m} \\ c_p &= 0.063\,\mathrm{MNs/m} \\ m_s &= 250\,\mathrm{kg} \\ k_b &= 1.5\cdot 10^2\,\mathrm{MN/m} \\ c_b &= 0.084\,\mathrm{MNs/m} \end{aligned}$$

Comparing two Figures, namely, 6 and 8, we can notice that for humps (*Fig. 6*) max. vertical accelerations are twice smaller than for hollows (*Fig. 8*). This fact was confirmed by measurements [2], too.

We have obtained the predicted results for one set of track parameters, such as equivalent masses, stiffnesses, etc. These parameters have an influence of different rate on wheelset-track interaction.

Nevertheless, fault sizes at rail welds and speed bring stronger effects than subgrade parameters.

It is possible to develop some computational studies in order to investigate into the sensitivity of wheelset dynamics on track component parameter variations.

As we mentioned above, a track is perfectly tangent beyond the weld fault area. This simplification is introduced to render the undisturbed influence of weld faults on the wheelset-track system. According to this, it is possible to determine permissible fault sizes (heights/depths), assuming for example, the same level of peak accelerations both in the weld area and on track span between welds.

Another way is the force criterion, when the limit of peak dynamic vertical wheel-rail force is to be determined. The criterion of acceleration

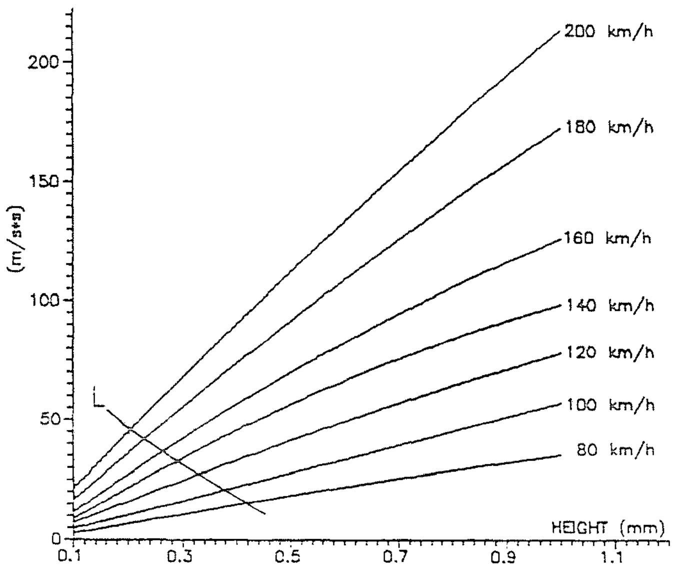

Fig. 6. Max. vertical wheelset accelerations (humps)

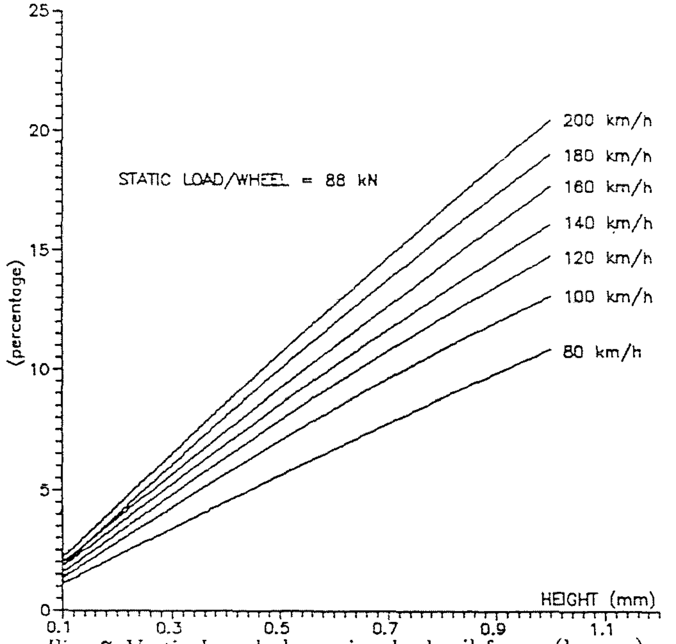

Fig. 7. Vertical peak dynamic wheel-rail forces (humps)

is more stringent than force criterion and first of all it gives sometimes practically unrealistic small values of hollow sizes [5]. Covering the limit curve representing, i.e. the maximum acceleration values between welds

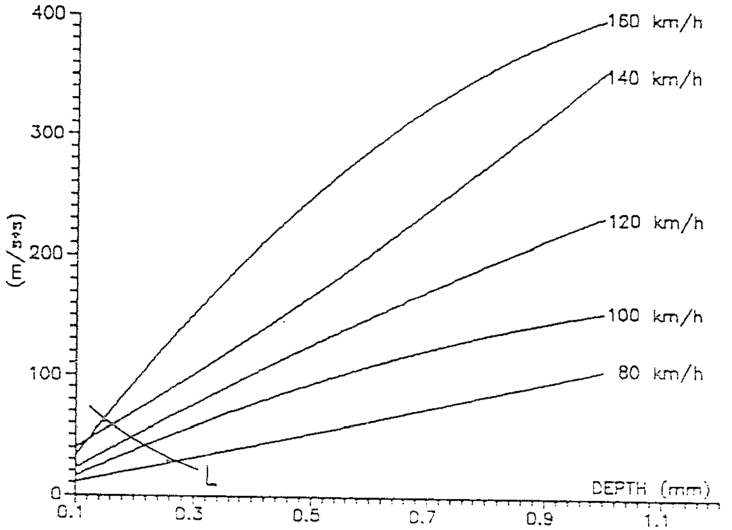

Fig. 8. Max. vertical wheelset accelerations (hollows)

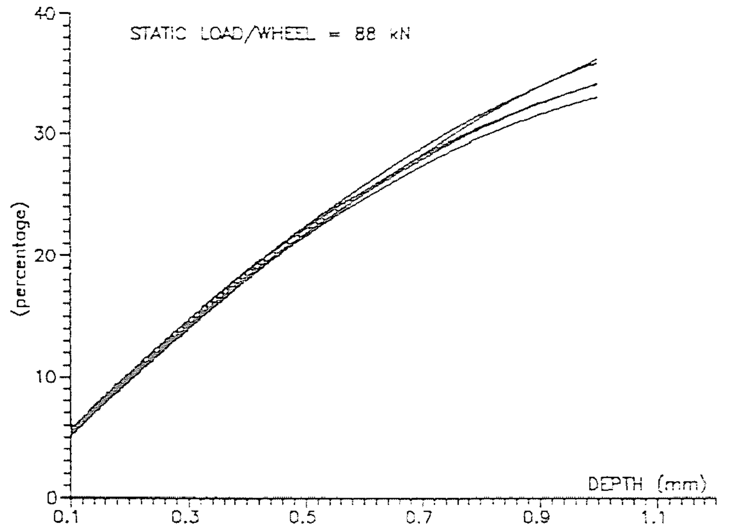

Fig. 9. Vertical peak dynamic wheel-rail forces (hollows)

in *Fig. 6* or *8*, we can obtain the permissible values of heights/depths in relation to speed.

According to the acceleration, it is allowed to predict permissible weld sizes for humps:

$$v \leq 160\,\mathrm{km/h}; \qquad 2h \leq 0.6\,\mathrm{mm},$$

$$v \leq 200\,\mathrm{km/h}; \qquad 2h \leq 0.4\,\mathrm{mm}.$$

The value $2h$ is often used as the results of measurement with the aid of 1 m straight-edge. (*Fig. 10*).

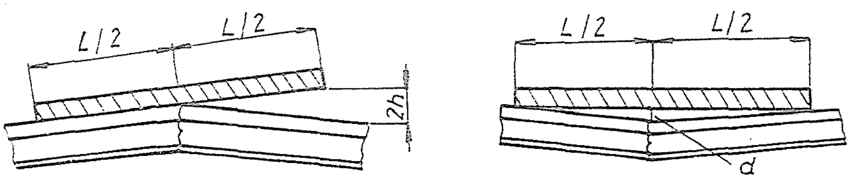

Fig. 10. Measurement of irregularities

For hollows the appropriate values of depths are nearly twice smaller than for humps ($2d \simeq h$), and therefore it is practically impossible to fulfil these tolerances. In a way similar to acceleration criterion, one can determine limit curve related to peak dynamic wheel-rail forces.

6. Conclusions

(1) Maximum unsprung mass accelerations on rail welds both for humps and hollows render powerful dependence on heights/depths of weld faults and on travelling speed.

(2) These geometrical weld faults have stronger effects on wheelset-rail dynamics than elastic-damping track component parameters.

(3) Peak dynamic wheel-rail forces on humps are significantly dependent on height and speed. For hollow welds, however, the forces are strongly dependent on depths and less on speed.

References

1. Ahlbeck, D. R. – Meacham, H. C.: The Development of Analytical Models for Railroad Tracks Dynamics. Pergamon Press, 1975.
2. Report, Analysis of Rail Roughness on the Experimental Track Section. Warsaw, MAG 1992 (unpublished).

3. SOWIŃSKI, B.: The Analysis of a Wheelset-Track System Vibrations. Ph. D. Thesis, Technical University of Warsaw, 1988.
4. Report ORE, Question D148 No. 3, Utrecht, September 1982.
5. Report ORE, Question D148 No. 6, Utrecht, April 1983.